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RESEARCH OF THE DEFECTIVE FROG WING OF 1/11 MARK

Summary. In this article, for the first time, research of the defective frog wing of the 1/11 mark on the Latvian Railway has been carried out. In the process of which was collected, processed and the analysis of points defects on the Latvian Railway was carried out for eight compartments of the track distance during 2014, 2015 and 2016 (Developed a chief of defectoscopy shop V. Glotov, approved CD the chief of the distance V. Makedon). The frog wing of the 1/11 mark (the 60 E1 DO 04 07 frog type) was considered according to the basic classification of the defects, and an analysis and research of the cause of its fracture were carried out.

INTRODUCTION

On the Latvian Railway, the Austrian manufacturer's "Voestalpine" point switches are widely used in which the frog structure is composed of an assembled rail that consists of two rails. The tongue of the frog consists of two sections of rails attached to each other, connected together by two wings, by a set of liners with bolts [1]. The frog mark 1/11 is often placed on the main and reception routes of the Latvian Railway. It allows the movement of trains along the straight track at speeds up to 90 km/h, and from the main track to the lateral direction of 50 km/h.

In Russian railways, solid frogs are used in point switches of type P65 of the 1/11 mark. They allow the movement of trains on a straight track up to 160 km/h. This solid frog consists of one part and is characterized by high strength and stability, but requires the use of large amounts of metal.

In 2014, 49 defective elements had been registered on the Latvian Railway. However, the number of defective elements decreased from 41 to 29 from 2015 to 2016 (Fig. 1).

The Latvian Railway is divided into eight sections of the track as follows: CDN-1 Sorting Department, CDN-2 Ciekurkalna Department, CDN-3 Daugavpils Department, CDN-9 Riga Department, CDN-5 Rezekne Department, CDN-6 Ventspils Department, CDN-7 Lepay Department and CDN-8 Jelgava Department.

The point switch frog is a special grooved structure designed to safely skip the crests of the wheels of rolling stock at the intersection of internal rail joints of two paths converging on the point switch (Fig. 2, 3).

The frog consists of two main elements:

– The tongue is a part installed in the place of convergence of internal rails.
– The wing is a part that allows the wheel pair to roll on the tongue from the connecting rails.

The fracture of one of the listed elements of the frog can lead to the descent of the wheel pair as well as to the collapse of the rolling stock. Based on the statistical data, it was decided to research frog wing 1/11 of type 60 E1 DO 04 07 (DO - Dowlais Steel Works, **04** – april month, **07** – 2007 year**)** under the code U.53.2. (Code U.53.2 is classified as U in the wing, 53. - cracks in the web from bolt or other holes in the rails, 2 - is outside the joint) [2]. It turned out that this problem is also present in other countries. In particular, in the Russian Railways "RZD", highly defective arrowheads under code U.53.2 are also present [3].

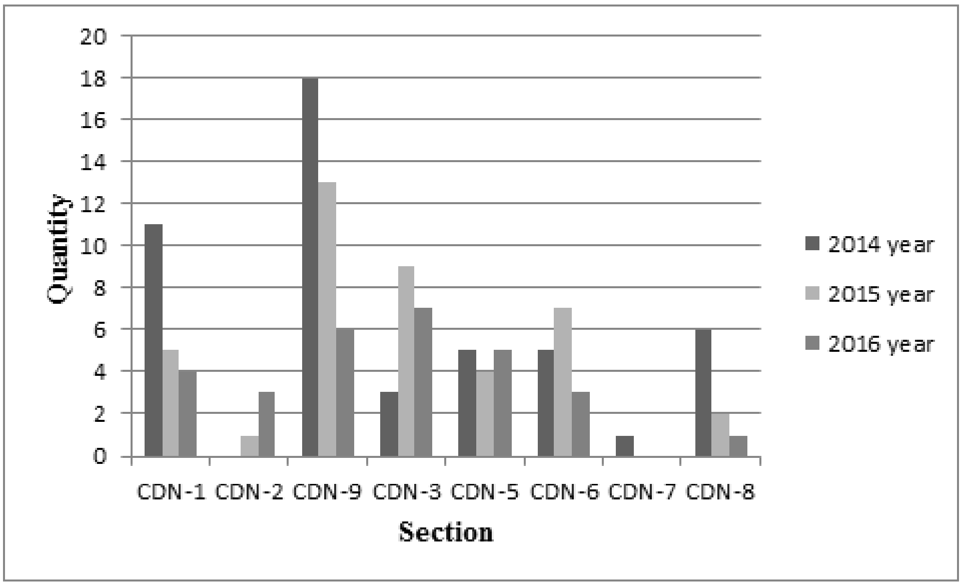


Fig. 1. Incidence of defective frog elements from 2014 to 2016

Fig. 2. Throat of wing

Fig. 3. Tail of the wing

Defects of rails and pointer elements register on the built-in hard disk of flaw detectors of type RDM-22, 23 with the subsequent transfer of data to the main computer through USB for register, process and analyze received information.

It follows from the diagram (Fig. 1) that, in 2014, the greatest number of rail defects was found in the CDN-9 Riga Department (18) and rail defects were not found in the CDN-2 Ciekurkalna Department. In 2015, 13 points defects were detected the Riga Department. Rail defects were not found in the CDN-7 Lepay Department for the whole year. In the previous year, 2016, the number of rail defects was reduced; in particular, only 7 rail defects were found in the CDN-3 Daugavpils Department. Rail defects were not found in the CDN-7 Lepay Department for the whole year.

The analysis of the statistics of the defects of point switches that had been carried out on the railways network of JSC RR [2] showed that the greatest numbers of defects were detected in the tongues of frogs of point switches. The distribution of defects by the elements of the point switches is shown in Fig. 4 [8].

– Defects of the wing (21.98%);
– Defects of switch point rails (14.44%);
– Defects of the tongue (51.43%);
– Defects of the point rail (10.88%);
– Defects of the track guard rail (1.27%).

In accordance with NTD/CP-1-93 [2] and in addition to NTD/CP-1-93 [3], the defects in point switches to be identified are classified according to the place of formation: in the point rails (DR); in contact tongues (DO); in the connecting ways (have the same character as in the rails of the normal profile); in the tongues of solid frogs (DS, DU); in solid tongues of frogs with welded rail ends; and in the wings and tongues of point swithes with a continuous surface of the skating (DUN, DSN).

Analyzing the problem of the defective rail elements on the railways, the following question emerges: how do these defects arise? It was decided to focus on one of the rail elements (defective frog wing 1/11 under code U.53.2) in order to analyze the state of the metal, to test it for hardness, assess the chemical composition, determine the metal structure and compare the obtained data with the manufacturer's data sheet [9].

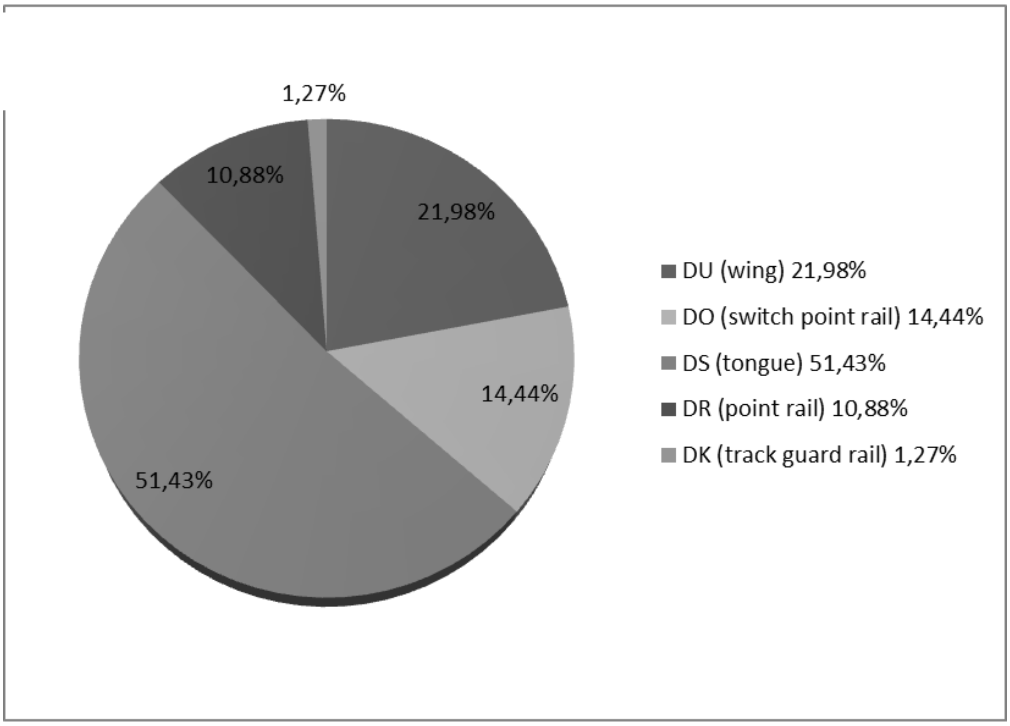


Fig. 4. Distribution of defects in point switches in the places of their formation in %

The defect code U.53. (Fig.5) is classified in the wing as cracks in the web from bolted or other holes in the rails and frog wings. Accordingly, the defect code U.53. is subdivided into the defect code U.53.1. and U.53.2., which means that U.53.1 is a defect of the wing in the joint and U.53.2 is a defect of the wing located outside the joint. Head chocks (small cracks) at the edges of the holes caused by drilling and corrosion accelerate the formation of a crack. The unsatisfactory condition of joints (weakening of bolts, subsidence in joints, the presence of large gaps) may be the main reason for the appearance and development of this type of defect [13].

The aim of this research was to study the broken defective frog wing of the 1/11 mark with the defect code U.53.2., type of the frog 60 E1 DO 04 07, rail type UIC 60, produced by Dowlais Steel Works [6] in April 2007. This specimen of the wing of the third bolted hole (Fig. 6) was broken from the frog throat to the entry points No. 1 of the Sece station of the Latvian Railway.

At the first stage of the research in the laboratory of the Riga Technical University, the rail steel was tested for hardness according to the Brinnel scale (HB). Krautkamer MIC 10 version hardness tester was used to carry out an analysis using the UCI method. The hardness test was performed according to the UCI standardized in accordance with ASTM A 1038. During the experiment, probes with test loads ranging from 1N (HV0.1) to 98N (HV10) were used. Before the experiment, the surface of the building was cleaned, sanded and polished according to the ISO 9001: 2008 standard. Using the modern device Krautkamer MIC 10, the values of the measurement results were independent of the probe position, even when measuring on the ceiling surface. The gauge can be used for hardness measurement of fine-grain materials of almost every shape and size, especially for local testing of material features [7]. During the course of the study, it was decided to determine the hardness of the weasel of the crosses in three places: the head, neck and sole. During the study, 35 points were measured, 17 on the top, 10 in the web and 8 at the base. The results of the measurements are shown in Fig. 7.

Fig. 5.The cut specimen of the wing under the defect code U.53.2

Fig. 6. The part of the cut broken wing (end view)

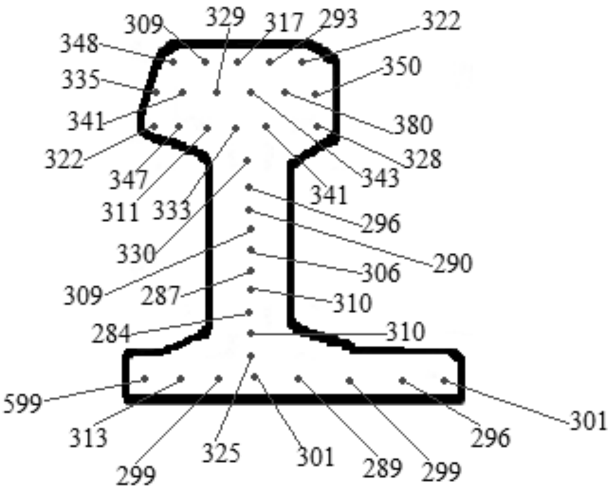


Fig. 7. Determination of hardness of the frog wing of the 1/11 mark with frog type 60 E1 DO 04 07 in HB:
at the wing top: 348, 309, 317, 293, 322, 335, 341, 329, 343, 380, 350, 322, 347, 311, 333, 341,328.
in the wing web: 330, 296, 290, 309, 306, 287, 310, 284, 310, 325.
at the wing base: 599, 313, 299, 301, 289, 299, 296, 301.

On the basis of the data obtained, a table was compiled and comparisons were made with the manufacturer's datasheet. The results of the comparisons are summarized in Table 1.

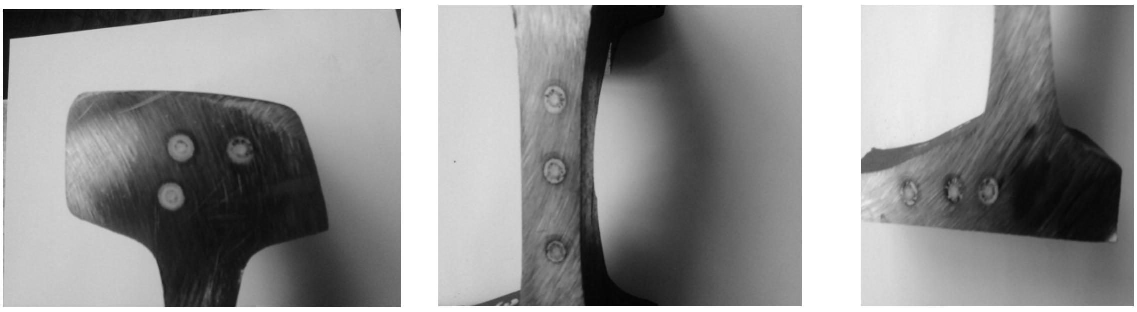
Table 1

Comparison of the hardness of the 60 E1 DO wing, with the steel grade R350HT, with the manufacturer's datasheet

Location of hardness determination	Rail hardness grade R350HT	
	Manufacturer's hardness (HB)	Medium hardness (the 60 E1 DO wing) (HB)
At the HB top	369	322
In the web	388	305
At the base	388	337

The average hardness in the wing top was 322 HB, which is 47 HB less than the permissible value of the manufacturer [8]. During testing, the medium hardness in the wing web was 305 HB, which is 73 HB less. Based on the results obtained, the average hardness in the base was 337 HB, which is 51 HB less than the specifications of theAustrian manufacturer [10].

In the second stage of the research, the chemical composition of the metal was analyzed at three points of the wing (top, web and base). The specimen of the defective wing was cut out from the frog wing to be examined using a circular saw. This specimen was ground (Fig. 8).



a) At the top b) In the web c) At the base

Fig. 8. Determination of the chemical composition in the three elements of the wing

To determine the chemical composition of the metal, an ARC-MET 8000 Mobile Lab optical emission analyzer was used [12]. Measurements were made at three different points, three times, at the top, in the web and at the base of the wing. The average results of the analysis of the chemical composition of the specimens are shown in Table 2.

Table 3 shows the datasheet of the chemical composition proposed by the Austrian supplier. In Table 4, the main permissible values of the chemical elements of the rail steel composition are summarized as percentage ratio.

In the chemical analysis, the average statistical data of the researches on the three points of the researched wing (tops, webs and bases) were processed [14]. The obtained data should be compared with the data of the manufacturer's specifications (see Table 3).

On comparing the basic, permissible values of chemical elements of the composition of rail steel, the following conclusion can be drawn: the carbon (C) content is greater by 0.089% than the manufacturer's specification.

The results of the researches showed that the content of (Mn) manganese was normal. The chemical element silicon (Si) was in the permissible percentage ratio. The chromium (Cr) content was higher than the established value, with a standard value of 0.0129%. The percentages of chemical elements such as phosphorus (P) and (S) sulfur were not within the allowable limits. The percentage of phosphorus (P) was more at 0.067% and the percentage of sulfur (S) was more than 0.0186%. The percentage value of such chemical elements as nitrogen (N) was not determined during the researches. The content of aluminum (Al) had increased by 0.0003% [5].

Table 2
The average values of the chemical composition of the researched frog wing (top, web and base) of the 1/11 mark of the frog type 60 E1 DO 04 07

VALUE	Fe	C	Si	Mn	P	S	Cr	Mo	Ni
MIN	-	0.850	0.250	0.900	0.0000	0.0000	0.0000	0.0000	0.0000
MAX	-	0.950	0.500	1.10	0.0350	0.0350	0.200	0.100	0.200
TOP	97.1	0.923	0.463	1.17	0.0635	0.0295	0.0944	0.0030	0.0312
WEB	97.2	0.863	0.441	1.15	0.0865	0.0353	0.0908	0.0030	0.0320
BASE	97.1	0.882	0.468	1.20	0.109	0.0420	0.0936	0.0030	0.0364
VALUE	Al	Co	Cu	Nb	Ti	V	W	Pb	Zr
MIN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
MAX	0.100	0.100	0.400	0.0700	0.0700	0.100	0.100	0.0700	-
TOP	0.0021	0.0065	0.0363	0.0030	0.0020	0.0058	0.0250	0.0100	0.0030
WEB	0.0020	0.0054	0.0363	0.0030	0.0020	0.0052	0.0250	0.0100	0.0030
BASE	0.0027	0.0062	0.0376	0.0030	0.0020	0.0059	0.0250	0.0004	0.0030

Table 3
Average values of the chemical composition of the Austrian manufacturer with the frog type 60 E1 DO

VALUE	C	Si	Mn	P	S	Al	H (ppm)	Cr	Ni
MIN	0.760	0.370	1.120	-	-	-	-	0.040	-
MAX	0.800	0.410	1.190	0.019	0.017	0.002	-	0.080	-
AVERAGE	0.780	0.390	1.170	0.014	0.012	0.001	0.700	0.060	0.030
VALUE	Cu+10Sn								
MIN	-								
MAX	-								
AVERAGE	0.040								

Table 4
Table of permissible deviations by chemical composition for railway elements not more than, in percentages %

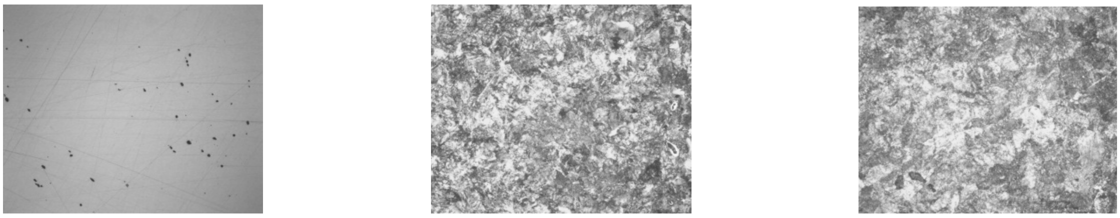
C carbon	Mn manganese	Si silicon	V vanadium	Cr chromium	N nitrogen	P phosphorus	S sulfur	Al aluminum
±0.02	±0.05	±0.02	+0.02	±0.02	±0.005	+0.005	+0.005	+0.001

During the course of determination of the chemical composition of the wing steel in the laboratory of the Riga Technical University, the following differences were found [15].

During the third stage of the research, the structure of rail steel was determined using a modern electronic microscope Carl Zeiss Axiovert 40 MAT optical microscope. Before the determination of the metal structure, the surface of the specimen was subjected to etching with a 5% solution of nitric acid $HN0_3$ [4]. The metal structure was determined under the microscope with the following magnification: the first specimen was examined by a (x100) magnification without etching the metal and the second specimen was examined by (x200) and (x500) magnifications with etching of the metal.

The obtained researches are shown in Fig. 10. As can be seen from Figure 10 (a), inclusions in the form of black spots were found in the metal structure. It can be assumed that the cause of the fracture was the presence of many inclusions in the metal because these inclusions could be a "nucleus" of the formation of cracks.

The metal structure was ferrite–pearlite. The ferrite–pearlite structure is a mixture of ferrite and cementite.



a) At magnification X100 b) At magnification X200 c) At magnification X500

Fig. 9. Determination of the metal structure under a microscope at different magnifications

CONCLUSION

1. In this paper, the main goal was achieved, namely, researching the hardness and the chemical composition, and determination of the metal structure of the defective wing and comparison of the obtained data with the manufacturer's standards.
2. Verification of hardness of the wing steel was carried out according to the Brinell scale (HB). The obtained data were compared with the data sheet of the Austrian manufacturer. The medium hardness of the wing (60E1DO) did not correspond to the manufacturer's data.
3. The chemical composition of the wing steel at the top, in the web and at the base was determined. The obtained data were compared with the data of the Austrian specifications EN 1367-2:2011 [16]. From the results it can be seen that there are deviations from the norms.
4. The results of the percentage content of such chemical elements as silicon (Si) and manganese (Mn) were within acceptable limits. The carbon (C), which is a main index, showed a slight increase of 0.089% in this metal and (Cr) chromium of 0.0129%. As is known, (C) carbon determines the hardness and strength of the metal.
5. The contents of such harmful chemical elements as (P) phosphorus and sulfur (S) were in inadmissible values and significantly affected the quality of rail steel.
6. Analyzing the metal of the frog wing of the 1/11 mark, a large inclusion was found, which indicates the low quality of the metal.
7. From the above researches it is possible to draw the following conclusion: the possible reason for a fracture of the defective frog wing of the 1/11 mark involved a number of factors, namely, the discrepancy of the metal hardness, the predominance in the metal of harmful chemical elements such as sulfur (S) and phosphorus (P), as well as the presence of many inclusions.

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